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Structure and Stratigraphy of China Basin[1]

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Abstract Continuous seismic reflection profiles accompanied by total-field magnetic measurements were made in the China basin by civilian survey ships on contract to the U.S. Navy Oceanographic Office between 1967 and 1969. The results show the presence of stratigraphic units similar to those previously found in the adjacent East China Sea and South China Sea: (1) acoustic basement in the southern part of the basin that may be a continuation of the igneous and metamorphic rocks beneath the adjacent shelf which were peneplaned during Late Cretaceous-early Cenozoic time, and much more irregular basement in the northern part of the basin that may be oceanic basement (Layer 2); (2) predeformational sediment, conformably with the surface of much of the acoustic basement (probably Paleogene); and (3) postdeformational sediment, largely turbidites deposited in deeper areas (probably Neogene to present) after the main episode of deformation. During the deformation a series of northeast-trending ridges was folded along the floor of the China basin. Similar ridges underlie the basin side slopes, and these served as dams to trap sediments brought to the ocean by streams from the adjacent land areas. Another ridge separates the Manila Trench and the West Luzon Trough, and extends northeastward as the Central Range of Taiwan. Oil potential appears to be greatest beneath the shelf between Taiwan and Hainan off mainland China, but the basin ridges that are surmounted by banks and islands also warrant further investigation.

Introduction

Since 1960 there has been a general increase of geologic interest in the continental margin along eastern Asia. Studies of sediments, stratigraphy, and structure have bordered or included parts of the China basin (Fig. 1), a large depression bordered clockwise by Taiwan, Philippine Islands, Borneo, Vietnam, Hainan, and mainland China (Fig. 2). Sediments of the shelf north of the China basin were described by Niino and Emery (1961), and of the shelf southwest of it by Emery and Niino (1963). In both areas the sediments were considered as chiefly relict from glacially lowered sea level and typical of the outer parts of most continental shelves of the world. An advance in the knowledge of the structure of the region came from broad reconnaissance seismic and magnetic surveys, first in the East China Sea (Emery *et al.*, 1969; Wageman *et al.*, 1970) and then in the South China Sea (Parke *et al.*, 1971) and in the Java Sea (Emery *et al.*, in press). Each of these geophysical studies showed the presence of tectonic ridges that served as submerged dams to trap sediments derived from adjacent lands. Only after several million cubic kilometers of Cenozoic sediments had accumulated in basins behind the dams were sediments able to escape in quantity over the dams and build thick sequences on the floor of the deep ocean or the China basin.

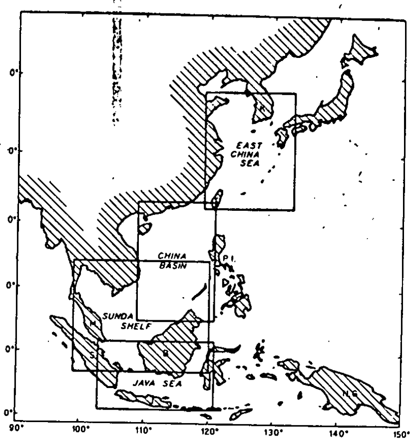

FIG. 1—Outlines of areas investigated in this and previous studies of China basin. Letters on land areas from north to south: *K*, Korea; *T*, Taiwan; *P.I.*, Philippine Islands; *M*, Malay Peninsula; *S*, Sumatra; *B*, Borneo; *N.G.*, New Guinea; *J*, Java.

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Appreciation is due the U.S. Naval Oceanographic Office through the interest of M. L. Parke, Jr., and L. M. Reynolds by providing the microfilms and other field records needed for this study. Copies of the seismic data are now available at the National Geophysical Data Center, and copies of the magnetic data are in the Magnetics Library, Naval Oceanographic Office. Financial support was provided by the National Science Foundation (Grant GA-27449) and the Office of Naval Research (Contract N00014-66-C0241). This is one of a series of geophysical studies conducted off eastern Asia in support of the United Nations Economic Commission for Asia and the Far East, and particularly of its Committee for Co-ordination of Offshore Prospecting.

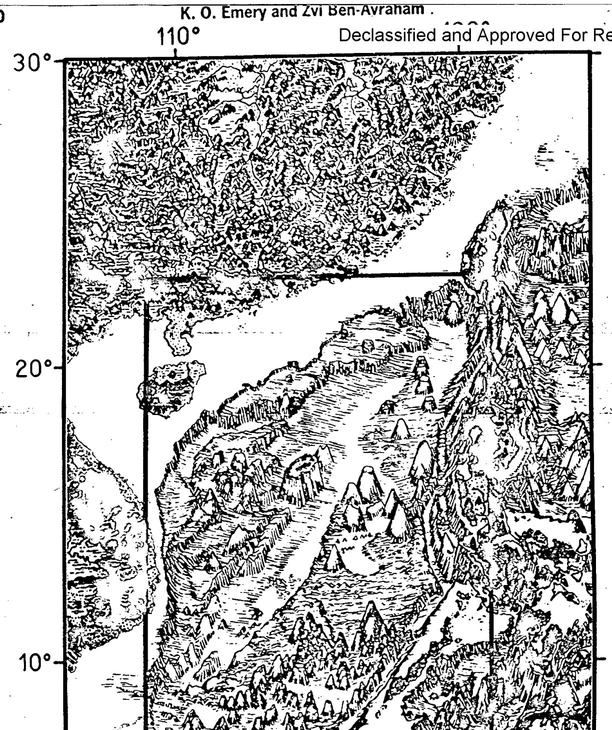

Fig. 2—Diagrammatic map of China basin and vicinity. Wide lines frame area portrayed in subsequent charts. From Heezen and Tharp (1971).

At the eastern side of the China basin, the bottom topography of the Manila Trench and the West Luzon Trough drawn by Irving (1951) and Dietz (1954) was updated by Ludwig *et al.* (1967) and by Chase and Menard (1969). Seismic profiles, made chiefly by geophysical ships of the Lamont-Doherty Geological Observatory arriving and departing Manila, used mainly half-pound charges of TNT as the sound source. The profiles of Ludwig *et al.* showed sediments about 1.5 km thick in the West Luzon Trough, of variable thickness in the Manila Trench, and 0-1.5 km thick on the floor of the eastern China basin where the nearly horizontal layers tended to smooth an irregular bottom that was identified as oceanic basement (or Layer 2). Hayes and Ludwig (1967) found that the trench and trough have negative free-air gravity anomalies, and magnetic anomalies that could not be traced over appreciable distances. Seismic velocity, measured at 13 refraction stations in the eastern China basin by Ludwig (1970), yielded 2.1-2.6 km/sec for sediments, and 4.4 km/sec for basement. Earthquakes are rare in the China basin except near the Philippine Islands (Gutenberg and Richter, 1949, p. 58-61; Hayes, and Ludwig, 1967) and east of Taiwan (Katsumata and Sykes, 1969). Most are shallow (less than 100 km) and exhibit little relation to known faults (Allen, 1962), but they do occur along a westward-dipping focal plane.

Between June 3 and August 26, 1969, a general geophysical study of the South China Sea (northern Sunda Shelf and southern China basin) was made aboard R/V *F. V. Hunt* on contract to the U. S. Navy Oceanographic Office from the Marine Acoustical Services of Miami, Florida. Transit to and from Chilung, Taiwan, plus traverses previously reported by Parke *et al.* (1971) in the southern end of the China basin, total about 8,900 line-km. All these traverses included seismic profiles using a 30,000-joule sparker with analog recording, and magnetic measurements using a proton-precession detector. Unknown to us at that time, additional seismic profiles with a 20,000-joule sparker, plus magnetometer measurements, had been made between September 15, 1967, and February 27, 1968, aboard *Ruth Ann* and *Santa Maria,* two ships of Alpine Geophysical Corporation of Norwood, New Jersey, on contract to the U.S. Navy Oceanographic Office (May *et al.,* 1969). About 9,400 km of fair to good seismic profiles are from traverses of *Ruth Ann* which, combined with the seismic profiles of *Hunt,* total 18,300 line-km. An additional 10,100 km of seismic profiles mainly from *Santa Maria* are poor in quality, but they yield somewhat more information than would simple bathymetric recordings. Geomagnetic records from all three ships plus four traverses from Project MAGNET total about 26,500 line-km.

Topography

Bathymetric contours of the China basin and vicinity (Fig. 3) were taken from the compilation by Chase and Menard (1969) through interpolation at 1-km depth intervals from their 200-fm contours. The chart also includes the 150-m contour to show the approximate position of the shelf-break. The widely spaced contours of Figure 3 fail to reveal many of the topographic details of Figure 2, but the two figures supplement each other. In contrast to the flat shelves, most side slopes of the China basin are very irregular owing to the presence of fault blocks, volcanoes, and calcareous reef structures. Fault blocks or slumps also are present low on the slope bordering the northwestern (mainland China) side of the basin, where they interrupt the surface of a basin rise. Smooth side slopes are present only at the southwestern end of the China basin, where Parke *et al.* (1971) showed the presence of sediment prograding northeastward from the adjacent northern Sunda Shelf.

On the floor of the basin are broad hilly areas—fault blocks, volcanoes, and calcareous reefs. The hilly area on the southwest includes Reed Bank and many smaller banks and reefs, many of which have been named for ships wrecked upon them—giving rise to the general name for this region as the Dangerous Ground. Another large area of hilly basin floor borders the western and northwestern side of the basin; it includes Macclesfield Bank, the Paracel Islands, and many smaller reefs. The Paracel Islands have a small village with a tower and meteorological station. This group and the other islets containing only temporary habitations and inadequate navigational aids are poorly mapped (U. S. Naval Oceanog. Office, 1967, p. 71-88) and have uncertain sovereignty.

The smooth prograded side slopes on the southwestern and to a lesser extent on the northeastern end of the China basin continue basinward as gently sloping aprons or basin rises that gradually flatten into abyssal plains. The largest abyssal plain occupies the central area of the basin, where the bottom is exceedingly flat at about 4,350 m. A much smaller abyssal plain floors the Palawan Trough near Borneo at about 2,850 m. Additional bottom contours that show the prograded sediments, their lower slopes, and their abyssal plains have been included on the

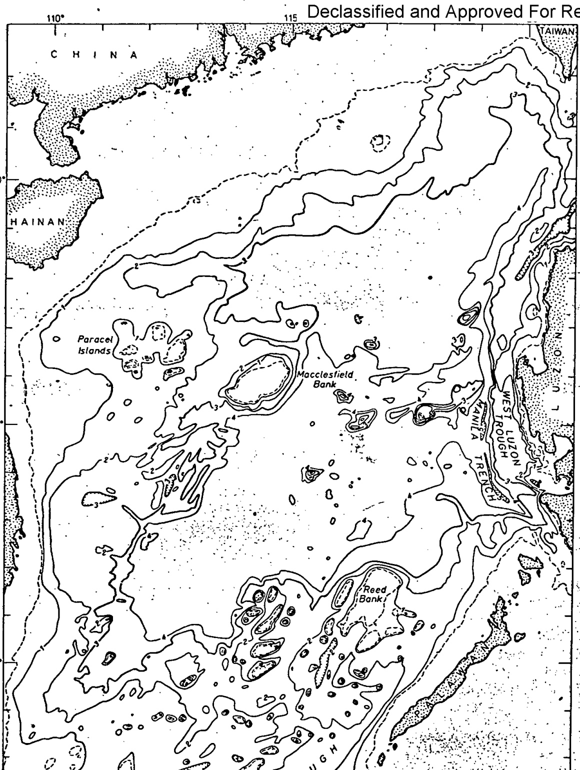

FIG. 3—Topography of China basin and adjacent shelves. CI = 1 km, with 150-m contour added as dashed line. Interpolated and redrawn from Chase and Menard (1969).

geologic map of the China basin (Fig. 15) as interpreted from available seismic profiles.

Sediments at the eastern side of the China basin slope downward from the nearly flat basin floor into the steep-sided Manila Trench; the southeastern end of the trench also has a smooth slope toward the 5,000-m deepest point just west of Luzon. East of the trench, the West Luzon Trough has a flat floor at about 2,600 m that may be blocked off from the deeper (about 3,200-m) floor of the northern extension of the steep-sided trough which has been termed the "North Luzon Trough" (Ludwig, 1970).

The entire area of Figure 3 is 2.7 million sq km, and the area of the China basin beyond the shelf-break is 1.8 million sq km—nearly one quarter the area of the conterminous United States.

Geomagnetics

Magnetometer data from R/V *F. V. Hunt, Ruth Ann, Santa Maria,* and airplane line Project MAGNET were digitized, and the regional gradient was removed by a computer program at Woods Hole Oceanographic Institution. The resulting lines of magnetic anomalies were plotted along the various traverses (Fig. 4). Anomalies in the southern, western, and northeastern parts of the basin are subdued, presumably because of the great depth that magnetic basement has been buried beneath sediments. Anomalies west of Luzon are larger, probably reflecting the presence of volcanic mountains that rise high above their surroundings. The degree of correspondence of magnetic anomalies with topography and structure is best shown on the geophysical profiles of Figures 6-11.

Seismic Profiles

The paper recordings of the continuous seismic profiles had been microfilmed and only flow-camera prints of the films were available to us. On these prints we marked in colored pencil the various kinds of reflecting surfaces. Only previous experience with the high-quality records from *Hunt* permitted identifications on many of the seismic records from *Ruth Ann* because of the generally lower power, poor microfilms, and short discontinuous traverses of the latter (Fig. 5). However, the final product from all three ships provides good coverage of the entire China basin in the form of structural sections.

The records revealed three main kinds of acoustic units, as already discussed by Parke *et al.* (1971) for the southern part of the basin. Deepest is acoustic basement, the deepest reflector for the available energy, and the one that is believed to consist largely of igneous rock—the oceanic basement, or Layer 2. Locally, volcanic peaks, massive coral reefs, and older folded sediments have similar reflective properties and must be included with acoustic basement. In the southern part of the China basin basement was peneplaned before being buried under sediments and then folded (Parke *et al.,* 1971, Figs. 21-23); this may be a northward continuation of pre-Cenozoic igneous and metamorphic rocks beneath the Sunda Shelf. Acoustic basement generally is buried beneath sediments, but locally it protrudes upward as isolated peaks or areas having very irregular topography.

Above the acoustic basement is a sedimentary blanket that follows many of the undulations of the basement. Elsewhere, it is folded and faulted, and abuts the steeper slopes of basement topography. The most intense folding is associated with basement projections and it forms a series of ridges that trend northeast-southwest. These ridges are crossed by the profiles of Figures 6-8, and are paralleled by those of Figures 9-11. Where the unit crops out, the topography is gently rolling and smoother than that for outcrops of acoustic basement (Fig. 12). Following the usage of Parke *et al.* (1971), the sequence is termed "predeformational sediment." This is somewhat simplified terminology, because at least two periods of deformation can be discerned locally through the presence of unconformities, but they cannot be traced for more than a few kilometers or correlated from place to place.

The third and shallowest consistent sequence occupies the troughs beneath the continental shelves (Fig. 13) and the areas of lowest topography within the China basin. Quite clearly, it is a sedimentary fill dating from the cessation of most diastrophic activity. This fill is termed the "post-deformational sediment," again in accordance with the terminology used in Parke *et al.* (1971), and in spite of the fact that in several profiles across this unit, some slight deformation is evident, caused by slumping or underthrusting along the Manila Trench (Fig. 14). The postdeformational sediments contain many good internal reflectors that are interpreted as sandy turbidites. In contrast, continuous discrete reflectors are less numerous in the pre-deformational sediment, which locally may even be acoustically transparent. The interpretation of the post-deformational sediment as being largely turbidite in origin accords with its distribution as a progradation from the continental shelves down the basin side slopes. Where sediment sources appear to be great, the post-deformational unit continues smoothly down the slopes in the form of narrow aprons whose slopes gradually merge into flat

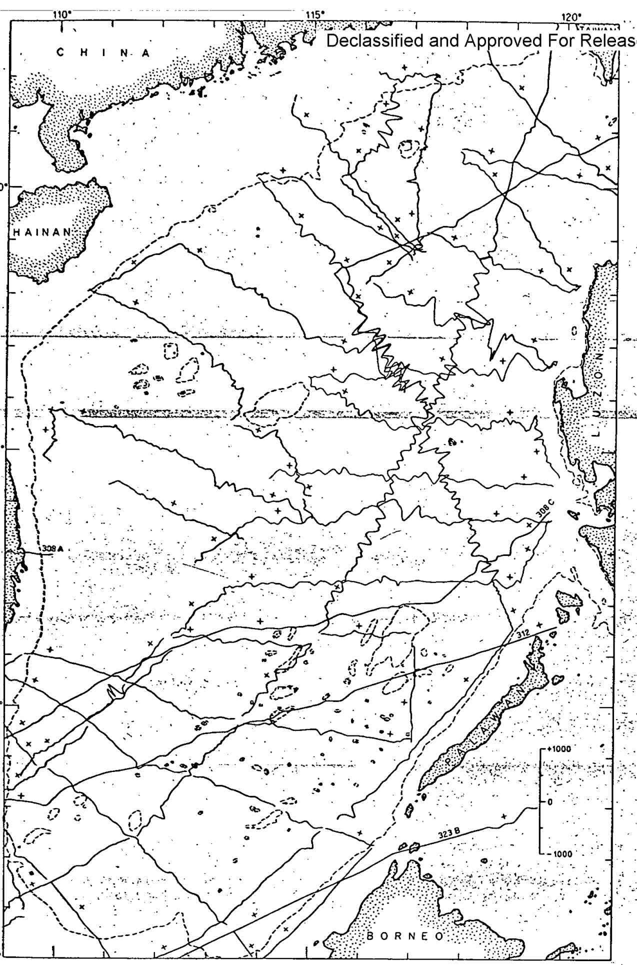

FIG. 4—Lines of magnetic anomalies from ship and airplane measurements across China basin. Four airplane lines (Project MAGNET)

abyssal plains in the deepest parts of the basins (Fig. 15). Detailed examination of bathymetric profiles by J. Mammerickx of Scripps Institution of Oceanography (personal commun.) revealed the longest apron to be cut by deep-sea channels with natural levees, particularly near lat. 12°N., long. 113°E.

The geologic map of Figure 15 also denotes the parts of seismic profiles that indicate outcrops of acoustic basement. Because these outcrops are small and discontinuous no attempt was made to group them. However, most of them are within the areas of predeformational sediment.

A generalized impression of the distribution pattern of the three stratigraphic units and their relation to the topography is given by the three-dimensional model of Figure 16. This model is viewed from the south, and it contains parts of profiles 9-9′, 10-10′, 11-11′, 12-12′, H-H′, J-J′, and L-L′. Careful inspection reveals several ridges composed of pre-deformational sediment and acoustic basement trending northeast, and separated by low, flat-bottomed areas underlain by post-deformational sediment.

Discussion

Geologic Dates

The major events recorded in the stratigraphy and structure of the China basin appear to be the peneplanation of acoustic basement and the folding that separates the predeformational and the postdeformational sediments.

The basement rocks of the Indochina Peninsula, the Malay Peninsula, Sumatra, and Borneo continue beneath the shallow Sunda Sea, and they consist mainly of Paleozoic and Mesozoic metamorphic and igneous rocks. A review of evidence for the Late Cretaceous age of the peneplain on acoustic basement south of the China basin is provided by Parke *et al.* (1971) and Todd and Pulunggono (1971). Magnetic (Bosum *et al.*, 1970) and gravity (Pan, 1967; Hsieh and Hu, 1971) surveys and drillhole samples from the Penghu Islands west of Taiwan (Huang, 1967; Chou, 1969) indicate that Mesozoic strata are far denser than Cenozoic ones, in agreement with the concept that the top of acoustic basement there could be the Late Cretaceous peneplain. In the Philippines a major unconformity also separates the Cretaceous and Tertiary Systems (Gervasio, 1966, 1968). No more specific evidence for the age of the acoustic basement rock or its peneplain is known from the China basin.

The large Northwest Borneo geosyncline contains thick, highly folded and faulted Paleogene sediments. Only sediments younger than middle Miocene have gentle dips. In this region the Paleogene sediments appear to have been deposited in deep water, and the late Neogene ones in shallow water, presumably the reverse of the depth sequence in the China basin (Parke *et al.*, 1971). In Taiwan, the Cenozoic sediments older than Pliocene are folded and faulted, and they form much of the Central Range (Juan and Wang, 1971). Lapping against them are thick "muddy sediments" of late Pleistocene age. The Miocene sediments are largely bedded sandstones with ripple marks; and the Pleistocene "muddy sediments" are massive mudstones, possibly of deep-water origin. In the Philippine Islands, as on Taiwan, there was a major tectonic episode during late Miocene time, followed by postorogenic sedimentation interrupted by volcanism and other tectonic activity (Gervasio, 1968). Uplifts and subsidence during the entire Cenozoic are well documented on the islands of Palawan, Mindoro, and Luzon; these movements resulted in cycles of arkosic marine sediments alternating with limestones. Folding and uplift have continued to the present along the eastern edge of the China basin, as indicated by raised Holocene calcareous reefs near the south end of Taiwan (Hashimoto *et al.*, 1970), by a 25-km left-lateral movement of the East Taiwan rift since late Pleistocene time (Biq, 1967), by the 1,200-km long left-lateral movement of the Philippine fault (Allen, 1962), and by the folding of "post-deformational" sediment in the Manila Trench (Fig. 14).

Until drill data are available from the floor of the China basin, we believe that the best age estimate for the unconformity at the top of the acoustic basement is Late Cretaceous. The main time of subsequent folding is probably early Neogene, with activity continuing to the present along the eastern side of the China basin.

Structural Implications

The distribution of the ridges beneath the outer edges of the continental shelves and across the floor of the China basin (Figs. 6-11, 16) is presented in simplified form in Figure 17. Ridges surround the basin, where they served as submerged dams to trap large quantities of detrital sediments brought to the ocean by rivers. One of the ridges bordering the shelf off Borneo continues northeastward as the elongate Palawan Island. These barriers appear to be close parallels with the ones previously observed in the East China Sea and the South China Sea. The ridge at the edge of the continental shelf off mainland China is known from only a few traverses, best of which is one by United Geophysical Corporation across the outer part of the shelf directly southeast of Hong Kong (Figs. 5, 13). In this area the

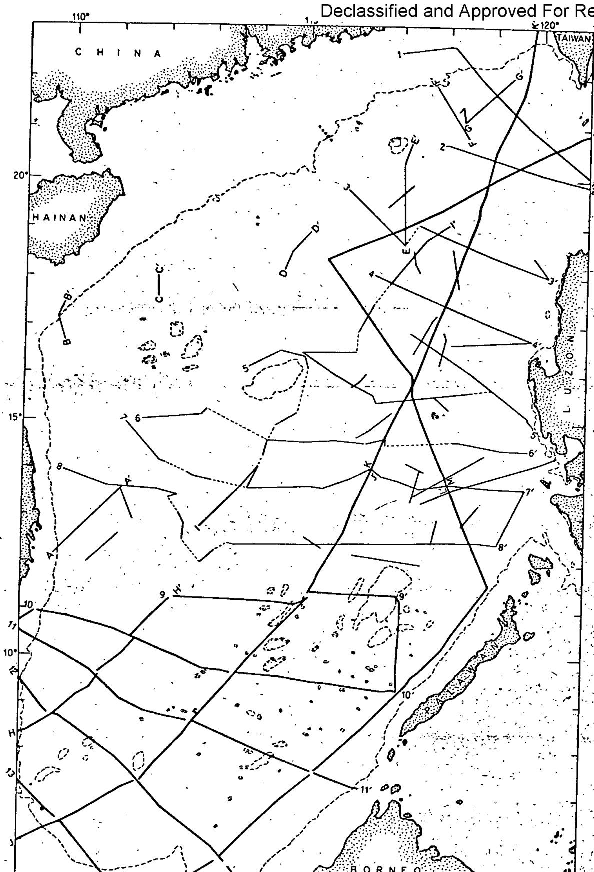

FIG. 5—Positions of best seismic profiles—from R/V *F. V. Hunt* (wide lines) and *Ruth Ann* (narrow lines). Dotted line across outer shelf at lat. 21°N, long. 115°E, is from United Geophysical Corporation (Fig. 13). Interpretive drawings are shown on Figures 6-11.

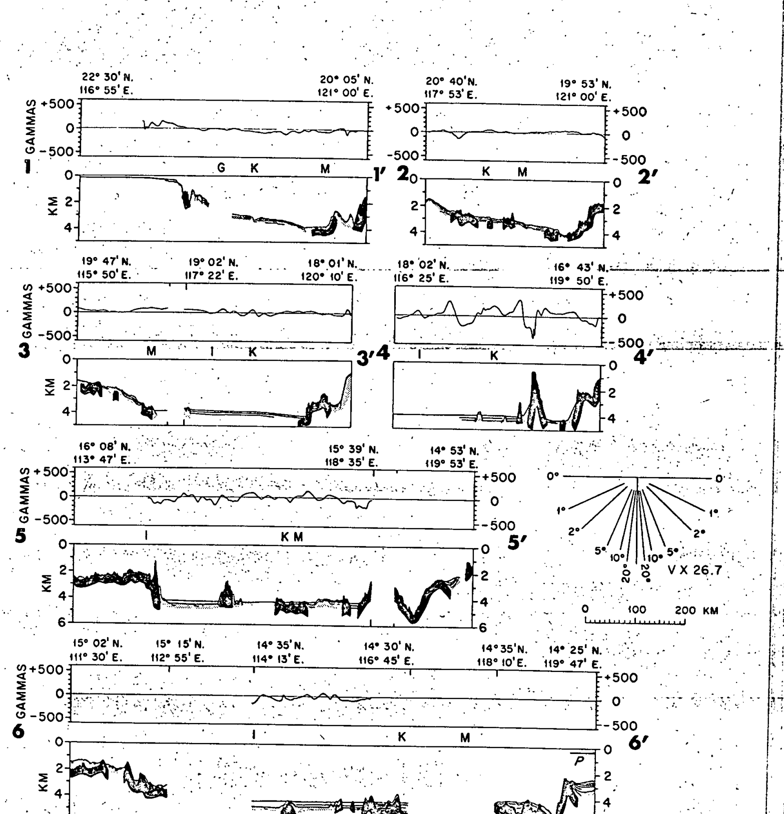

FIG. 6—Interpretative seismic and magnetic profiles along traverses 1-1′, 2-2′, 3-3′, 4-4′, 5-5′, and 6-6′ (Fig. 5), assuming acoustic velocity of 1.5 km/sec in water and 2.0 km/sec in sediments. *Top:* Total intensity magnetic anomalies. *Bottom:* Line-drawing interpretation of continuous seismic reflection profiles, vertical exaggeration 26.7x. Black indicates acoustic basement; coarse dots, predeformation sediments; and fine dots, postdeformation sediments. Small horizontal bar and *p* designate part of recording illustrated by photograph.

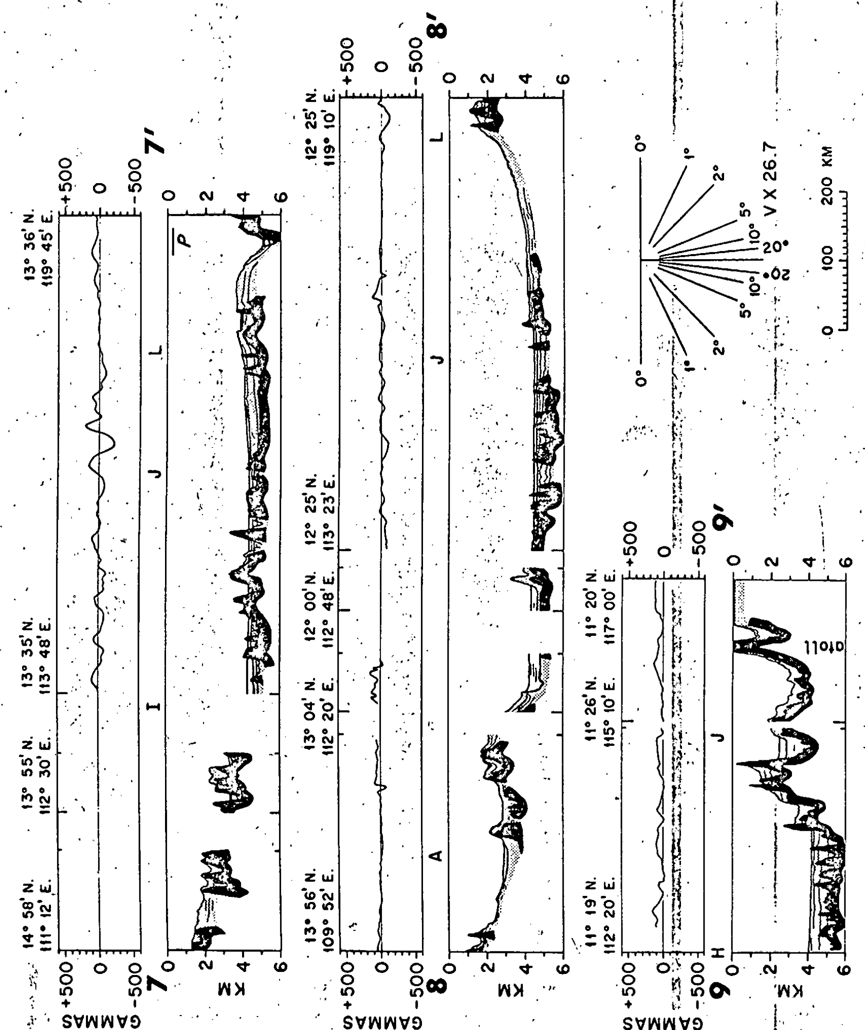

Fig. 7—Traverses 7-7′, 8-8′, and 9-9′. Symbols are same as for Figure 6.

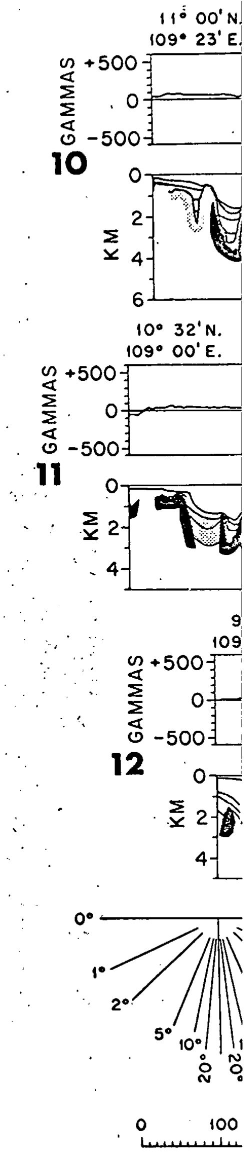

Fig. 8

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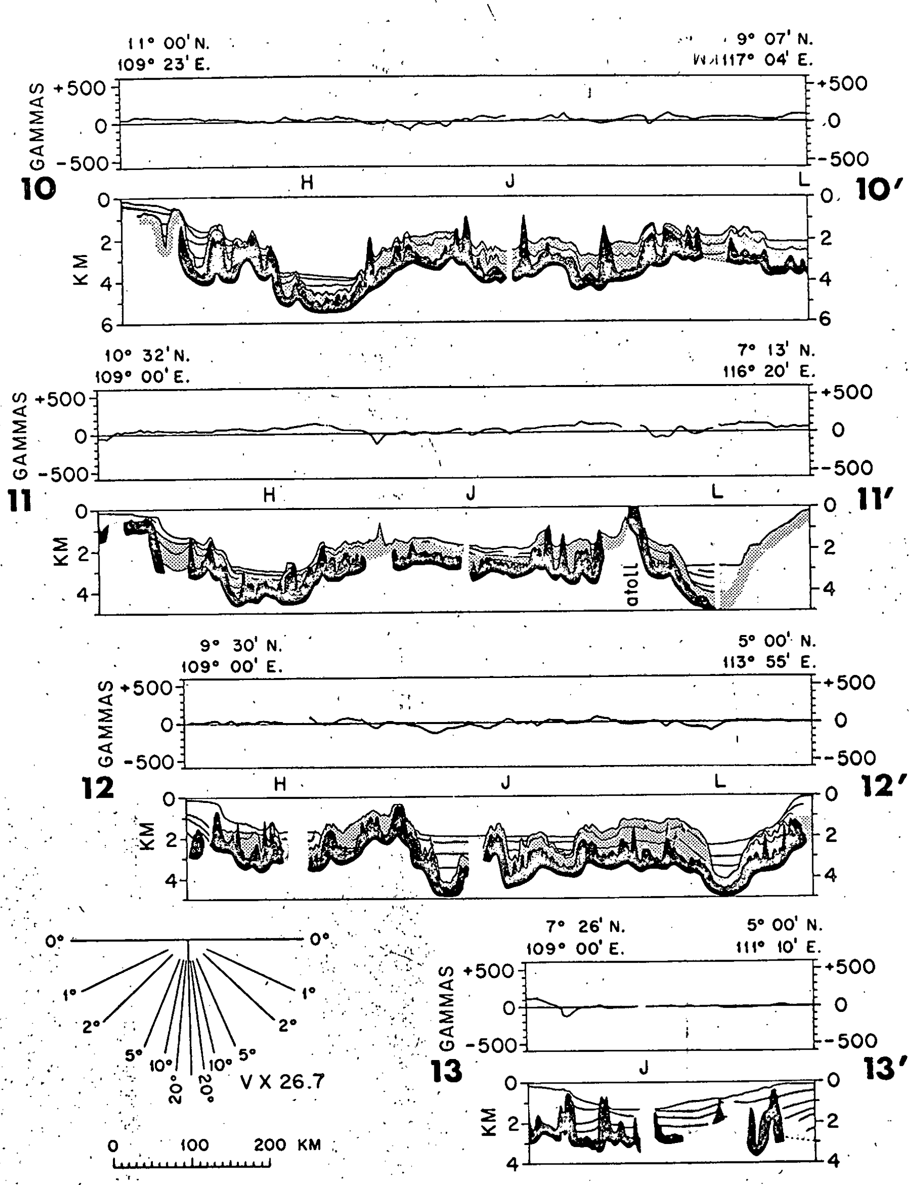


FIG. 8—Traverses for 10-10', 11-11', 12-12', and 13-13'. Symbols are same as for Figure 6.

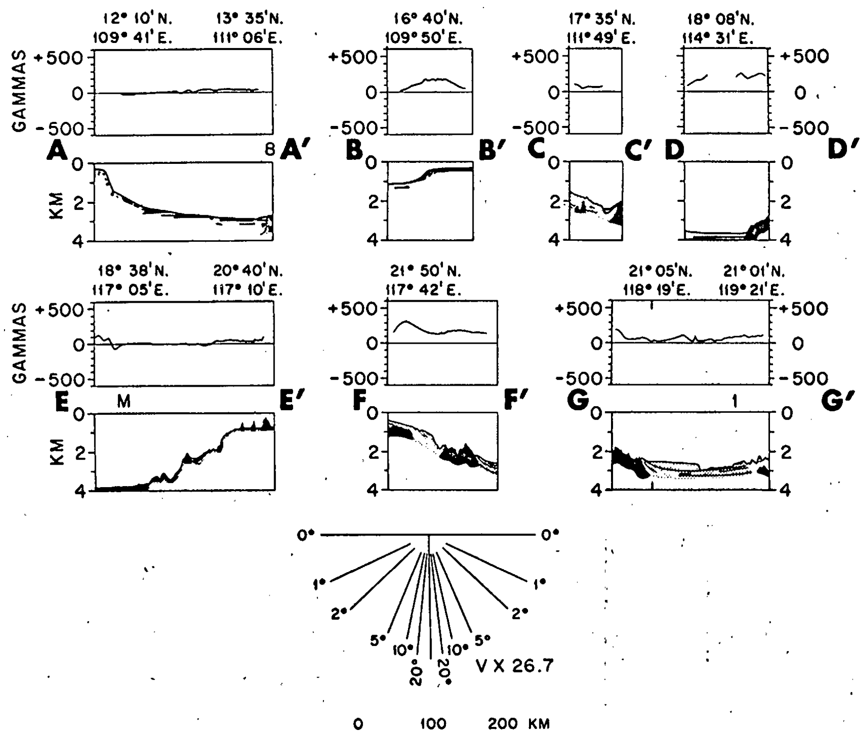
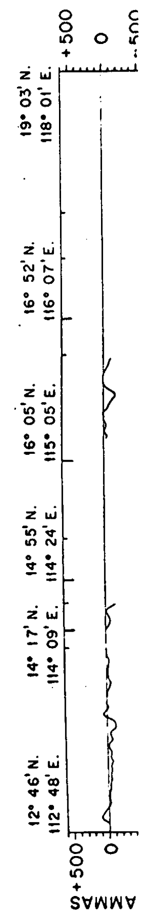


Fig. 9—Traverses A-A', B-B', C-C', D-D', E-E', F-F', and G-G'. Symbols are same as for Figure 6.



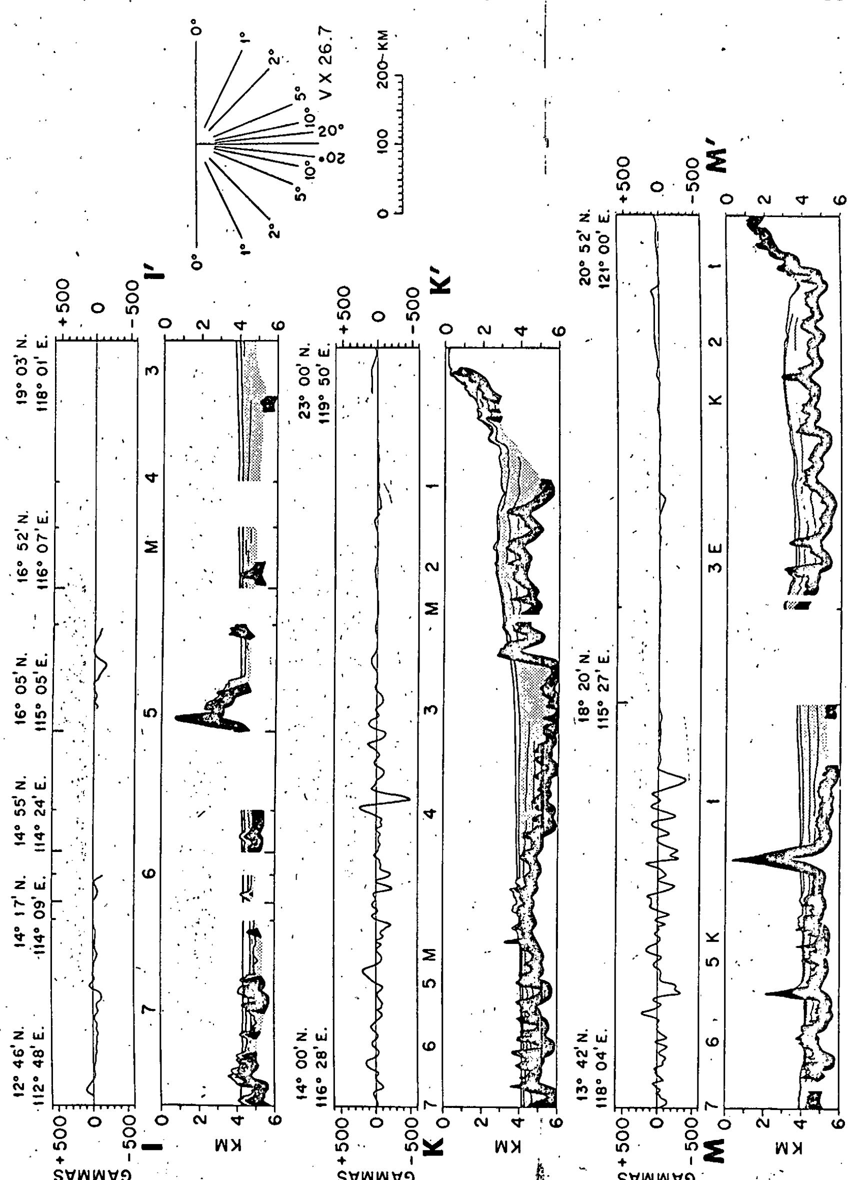


FIG. 10—Traverses I-I', K-K', and M-M'. Symbols are same as for Figure 6.

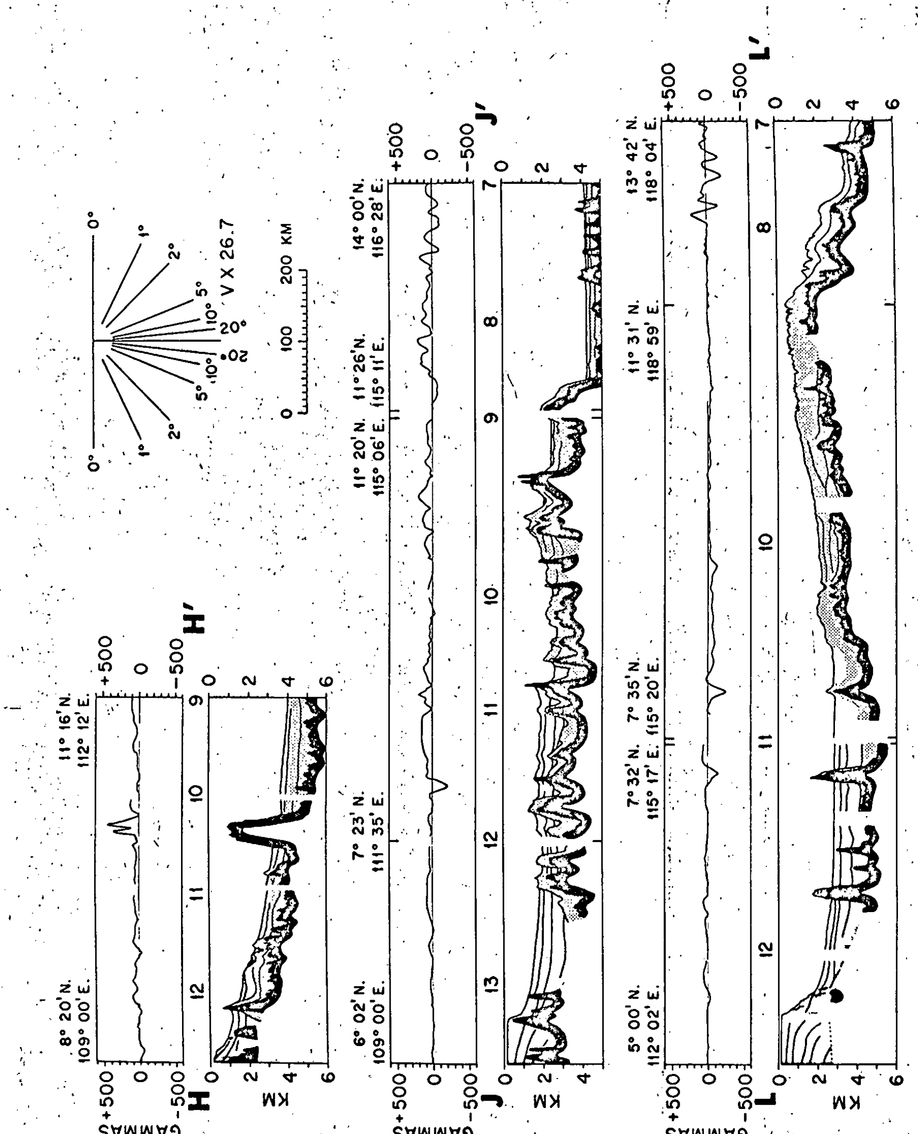
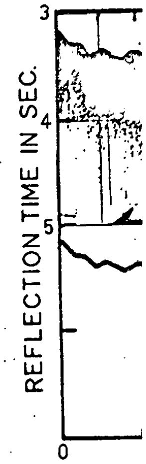


Fig. 11—Traverses H-H′, J-J′, and L-L′. Symbols are same as for Figure 6.



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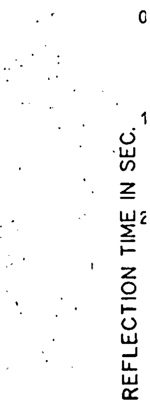

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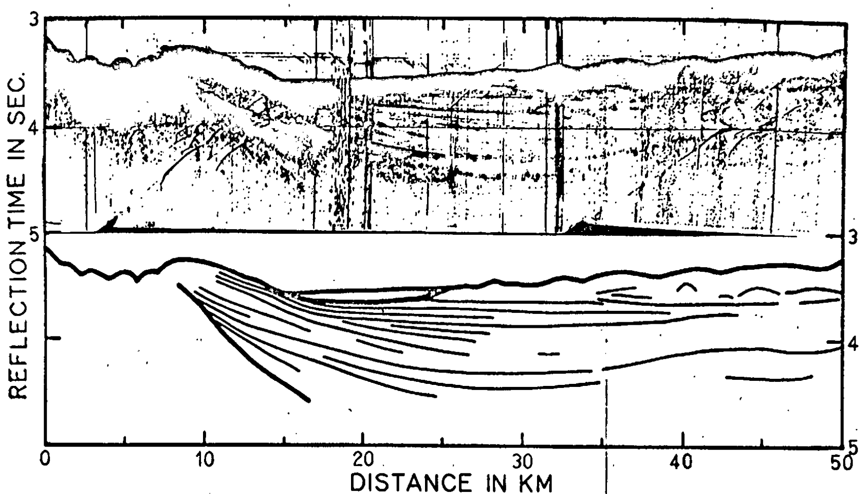

FIG. 12—Section of seismic recording and of its interpretation showing repeated westward thinning of sediments in West Luzon Trough (profile 6-6′ of Figure 6 at lat. 14°25′, long. 119°35′) caused by repeated uplift of bordering ridge.

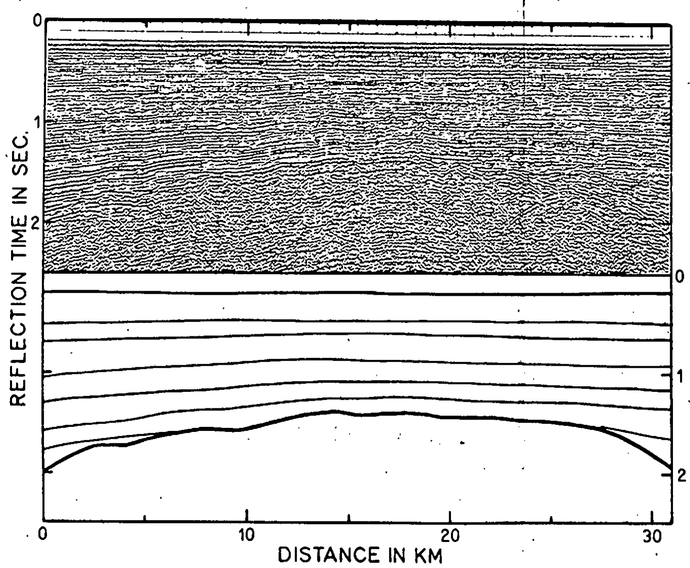

FIG. 13—Section of seismic recording across outer part of continental shelf southeast of Hong Kong (Fig. 5) showing barrier ridge beneath outer shelf backed by thicker sediments trapped by ridge. This seismic section was provided by United Geophysical Corporation and was electronically enhanced by GEOCOM Corp.

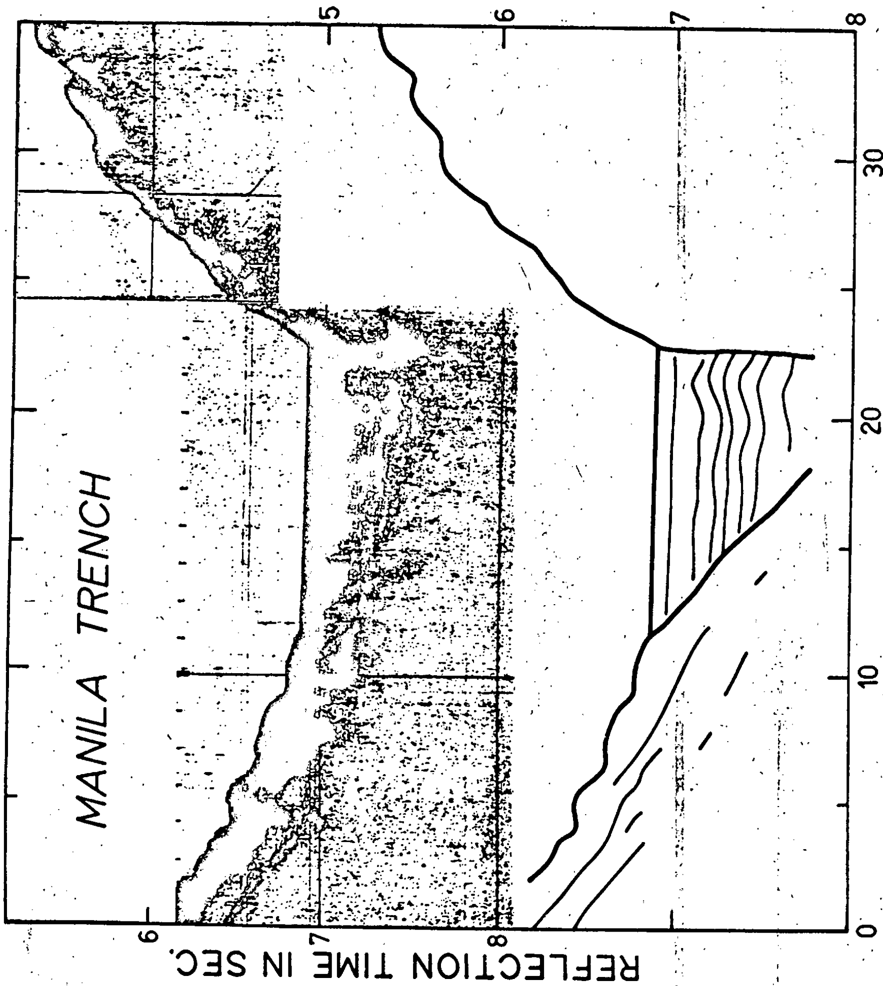

FIG. 14—Section of seismic recording and of its interpretation showing slight folding of postdepositional sediments in Manila Trench (profile 7-7′ of Fig. 7 at lat. 13°24′, long. 119°38′) caused by underthrusting.

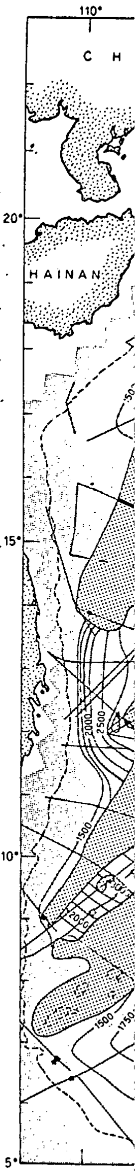

FIG. 15—Geologic ma
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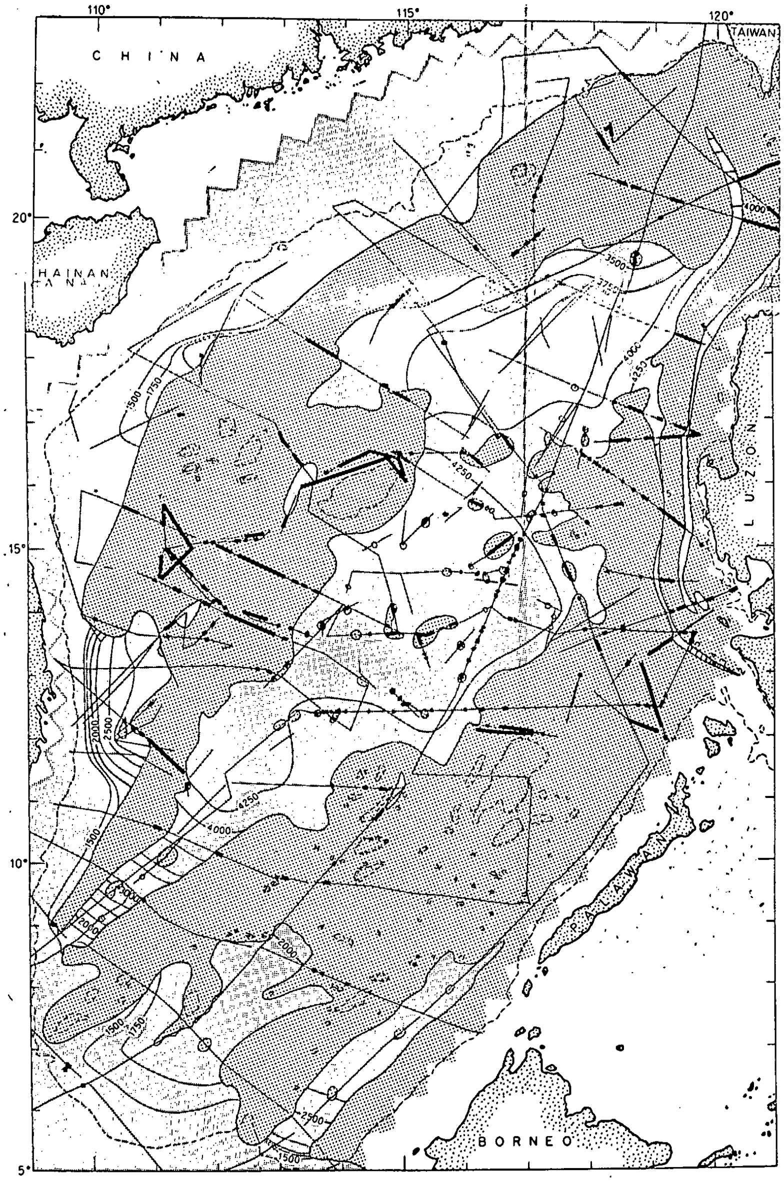
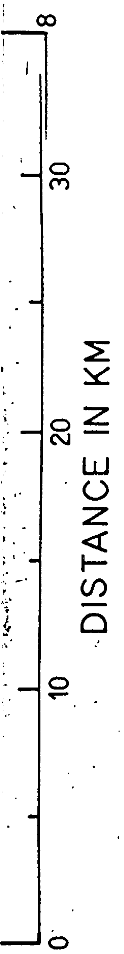


Fig. 15—Geologic map showing areas of postdeformational sediments (fine dots) with topographic contours at 250-m depth intervals. Exposed predeformational sediment in areas of positive relief. Outcrops of acoustic basement shown by seismic profiles are so discontinuous that they are drawn only as wide parts of lines that denote positions of traverses. Many more traverses are shown as control for geologic map than were useful as structural sections (Fig. 5).



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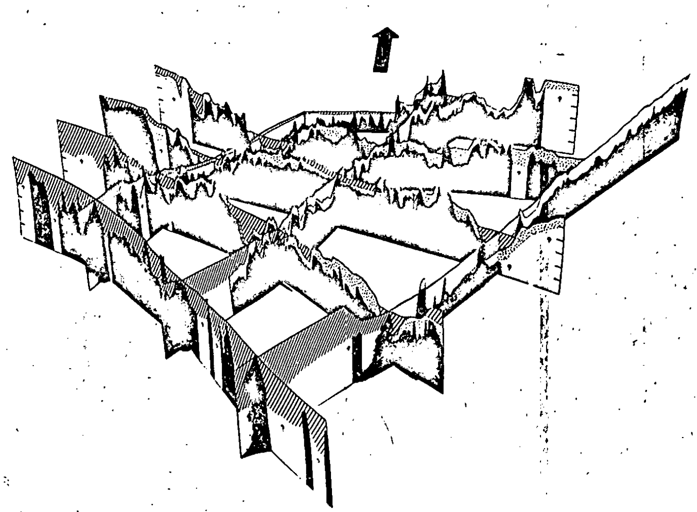


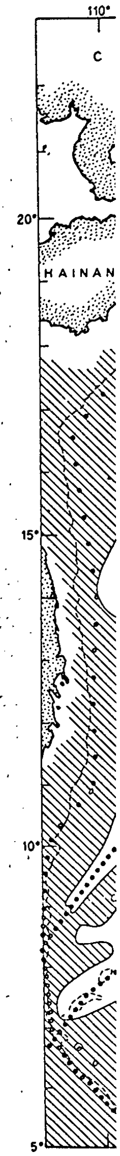
Fig. 16—Photograph of three-dimensional cardboard model depicting acoustic basement in black; predeformational sediment, dotted; postdeformational sediment, diagonally hatched. Broad arrow at top indicates north. Parts of profiles 9-9', 10-10', 11-11', 12-12', H-H', J-J', and L-L'.

ridge is buried beneath about 1.4 km of sediments that are much thicker on either side of the ridge (Fig. 13).

Other ridges on the floor of the basin are best known where post-deformational sediments are absent or thin, and they trend northeast except along the easternmost edge of the basin, where the trend is northerly. As shown by the structure sections, the ridges are complexly folded and faulted, and some appear to be penetrated by volcanic peaks. At the northeastern and southwestern ends of the China basin the northeast-trending ridges are truncated by other ridges or are buried beneath later sediments that have prograded basinward. The small acoustic power source and the restriction to analog recording (that could not remove bottom multiples) prevent their clear recognition beneath the thick sediments of the shelves. However, one very long and nearly continuous ridge appears to extend northeastward beneath Formosa Strait (between Taiwan and the mainland). It may underlie and be the origin of the Penghu Islands (lat. 23°35'N, long. 119°35'E), in which a drillhole shows the presence of hydrothermally altered Mesozoic and Paleogene sedimentary rocks and of Pliocene-Pleistocene tuffs and basalts (Huang, 1967). This significance, however, may be reduced by the frequency of igneous rocks of many ages on Taiwan (Yen, 1971).

The Central Range of Taiwan (Fig. 17) appears to be a northerly continuation of a ridge that, farther south, separates the Manila Trench and the West Luzon Trough, and may continue southeastward through the central Philippine island of Mindoro (Philippines Bureau of Mines, 1964). This interpretation differs from that of Bosum *et al.* (1970) and Juan and Wang (1971), who believed that the structures of Taiwan are separated from those of the Philippines by a fracture zone, and that of Meng and Chang (1971), who lacked submarine data and suggested that the structures on land in both Taiwan and the Philippines are directly connected. The relation of the large strike-slip fault of the Philippines (Allen, 1962) to that of Taiwan (Biq, 1967) is unknown.

The pattern of subparallel folded ridges along the length of the China basin strongly suggests that the last major deformation was compression along a southeast-northwest axis through the China basin, not the tension that was earlier suggested by van Bemmelen (1949) and Rodolfo (1969). The compression is easier to visualize in



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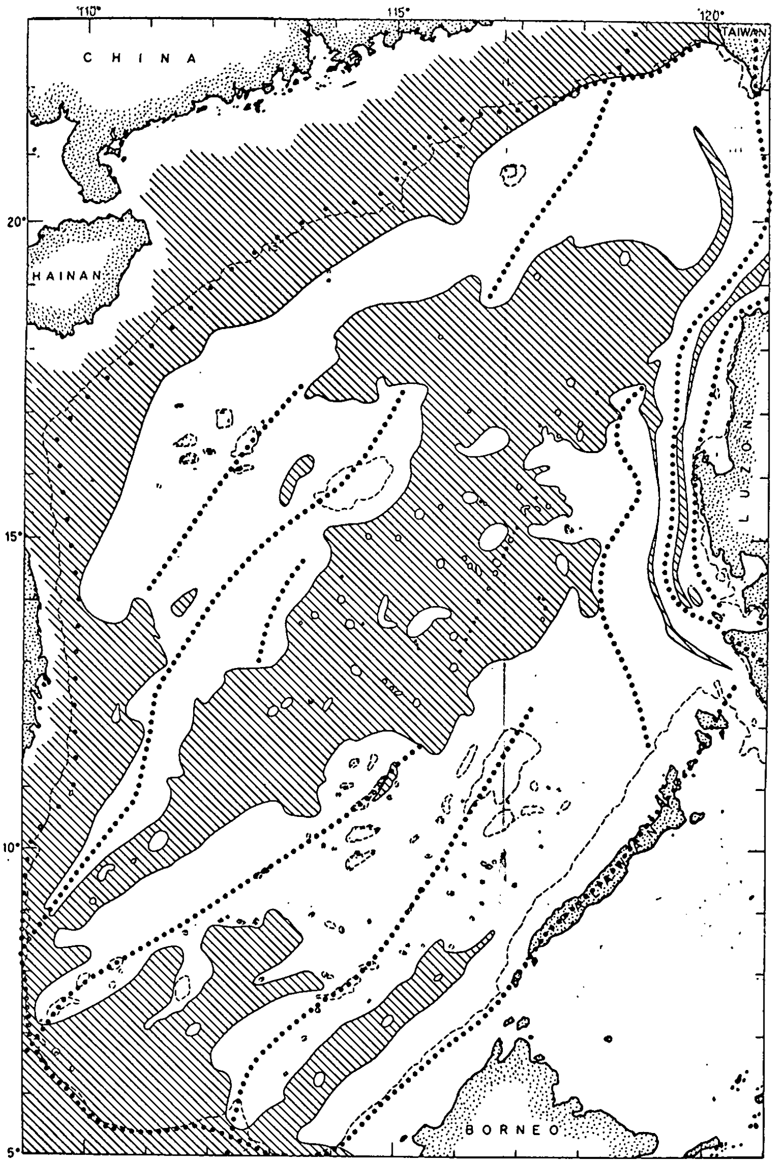

FIG. 17—Pattern of ridges (dotted lines) peripheral to China basin and passing diagonally through it. Hachures depict areas of postdeformational sediments shown in more detail on Figure 15.

terms of sea-floor spreading, whereby the Philippine plate beneath the Pacific Ocean is underthrusting continental plates of southeastern Asia in the manner suggested by Isacks *et al.* (1968), Le Pichon (1968), Morgan (1968), and Oliver (1970). Underthrusting south of lat. 14°N appears to occur in the Philippine Trench, which extends along the southern part of the east side of the Philippine Islands. Farther north, the underthrusting is in the Manila Trench west of the northern part of the Philippines, indicating that a small segment of the Philippine Plate is pushing westward into the China basin (Dewey and Bird, 1970). The two trenches on opposite sides of the islands must be separated by a fault, as suggested by Fitch (1970). Active underthrusting accounts for the repeated uplift of the ridge bordering the West Luzon Trough (Fig. 12), the slight folding of sediments in the Manila Trench (Fig. 14), and the westward overthrusting on Taiwan described by Meng and Chang (1971). West of Luzon three ridges trend northward and parallel the Manila Trench. The similarity of trend suggests that these three ridges are active and thus are younger than the northeast-trending ridges farther west in the China basin.

Oil Potential

Oil exploration activity during 1969 and 1970 was confined to the marginal areas shown in Figure 17 and to a few seismic lines on Reed Bank; several holes were drilled off northwestern Borneo and off northwestern Palawan in the Philippine Islands (Humphrey, 1970, 1971). Activity in mainland China is confined to land areas (Meyerhoff, 1970) with limited geologic interest exhibited so far in the offshore region bordering the China basin.

The results of this geophysical study suggest that the thickest Neogene sediments (the age of the producing zones in Taiwan) are likely to be present in the filled marginal trough that underlies the continental shelf between Taiwan and Hainan, mostly off the southern coast of mainland China. The oil potential of the linear ridges that underlie the outer edges of the continental shelves and cross the floor of the China basin is of even more speculative interest. The islands and banks that cap many of the ridges could serve as drilling platforms, but nothing is known of the organic content and reservoir charactertistics of the folded and faulted, probably Paleogene strata that cap the acoustic basement and form the ridges themselves.

Clearly, more closely spaced geophysical traverses are needed across the shelf and the ridges before further speculation is warranted about oil potential of the region.

References Cited

Allen, C. R., 1962, Circum-Pacific faulting in the Philippines-Taiwan region: Jour. Geophys. Research, v. 67, p. 4795-4812.

Biq, C. C., 1967, The east Taiwan rift: Taiwan Petroleum Geology, no. 4, p. 93-106.

Bosum, W., G. D. Burton, S. H. Hsieh, E. G. Kind, A. Schreiber, and C. H. Tang, 1970, Aeromagnetic survey of offshore Taiwan: Bangkok, U.N. ECAFE, Comm. for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Tech. Bull., v. 3, p. 1-34.

Chase, T. E., and H. W. Menard, 1969, Bathymetric atlas of the northwestern Pacific Ocean: U.S. Naval Oceanog. Office, 50 sheets.

Chou, J. T., 1969, A petrographic study of the Mesozoic and Cenozoic rock formations in the Tungliang well TL-1 of the Penghu Islands, Taiwan, China: Bangkok, U.N. ECAFE, Comm. for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Tech. Bull., v. 2, p. 97-115.

Dewey, J. F., and J. M. Bird, 1970, Mountain belts and the new global tectonics: Jour. Geophys. Research, v. 75, p. 2625-2647.

Dietz, R. S., 1954, Marine geology of northwestern Pacific: description of Japanese bathymetric chart 6901: Geol. Soc. America Bull., v. 65, p. 1199-1224.

Emery, K. O., and H. Niino, 1963, Sediments of the Gulf of Thailand and adjacent continental shelf: Geol. Soc. America Bull., v. 74, p. 541-554.

——— Y. Hayashi, T. W. C. Hilde, K. Kobayahsi, J. H. Koo, C. Y. Meng, H. Niino, J. H. Osterhagen, L. M. Reynolds, J. M. Wageman, C. S. Wang, and S. J. Yang, 1969, Geological structure and some water chacteristics of the East China Sea and the Yellow Sea: Bangkok, U.N. ECAFE, Comm. for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Tech. Bull., v. 2, p. 3-43.

——— E. Uchupi, J. Sunderland, H. L. Uktolseja, and E. M. Young, in press, Geological structure and some water characteristics of the Java Sea and adjacent continental shelf: Bangkok, U.N. ECAFE, Comm. for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Tech. Bull., v. 6.

Fitch, T. J., 1970, Earthquake mechanisms and island arc tectonics in the Indonesian-Philippine region: Seismol. Soc. America Bull., v. 60, p. 565-591.

Gervasio, F. C., 1966, A study of the tectonics of the Philippine archipelago: Philippine Geologist, v. 20, p. 51-75.

——— 1968, Age and nature of orogenesis of the Philippines: Bangkok, U.N. ECAFE, Comm. for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Tech. Bull., v. 1, p. 113-128.

Gutenberg, B., and C. F. Richter, 1949, Seismicity of the earth and associated phenomena: Princeton, New Jersey, Princeton Univ. Press, 273 p.

Hashimoto, W., K. Taira, K. Kurihara, T. Imai, and Y. Makino, 1970, Studies on the younger Cenozoic deposits in Taiwan (Formosa): Pt. 1. The younger Cenozoic deposits of the middle part of west Taiwan: Southeast Asia Geology and Palaeontology, v. 8, p. 237-252.

Hayes, D. E., and W. J. Ludwig, 1967, The Manila Trench and West Luzon Trough—2. Gravity and magnetics measurements: Deep-Sea Research, v. 14, p. 545-560.

Heezen, B. C., and M. Tharp, 1971, Physiographic diagram of the western Pacific Ocean: Geol. Soc. America.

Hsieh, S. H., and C. C. Hu, 1971, Gravimetric and magnetic studies of Taiwan: Taipei, Taiwan, Sino-American Science Cooperation Colloquium on Ocean Resources, v. 1, Marine geology and geophysics, p. 87-145.

Huang, T., 1967, Foraminif
I of the Penghu Islands:
p. 131-149.

Humphrey, W., 1970, Petr
1969: Am. Assoc. Petrol
1566.

——— 1971, Petroleum d
Am. Assoc. Petroleum G

Irving, E. M., 1951, Subm
archipelago and its geo
Sci., v. 80, p. 55-88.

Isacks, B., J. Oliver, and L.
new global tectonics: J
5855-5899.

Juan, V. C., and Y. Wang
tectonic framework of t
Sino-American Science
Resources, v. 1, Marine g

Katsumata, M., and L. R.
of the western Pacific:
Taiwan regions: Jour
5948.

Le Pichon, X., 1968, Sea-fl
Jour. Geophys. Research,

Ludwig, W. J., 1970, The
Trough—3. Seismic-refra
search, v. 17, p. 553-571.

——— D. E. Hayes, and
and West Luzon Trough-
bution: Deep-Sea Resear

May, M., R. A. Wehnau,
Marine geological survey
cific Ocean and South
operations, measurement
dures: Norwood, New Je
98 p. (multilithed).

Meng, C.-Y., and S. S. L.
of Taiwan: Taipei, Taiwa
tion Colloquium on Oce

Huang, T., 1967, Foraminiferal study of the Tungliang well TL-1 of the Penghu Islands: Taiwan Petroleum Geology, no. 5, p. 131-149.
Humphrey, W., 1970, Petroleum developments in Far East in 1969: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 1551-1566.
——— 1971, Petroleum developments in Far East in 1970: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 1634-1656.
Irving, E. M., 1951, Submarine morphology of the Philippine archipelago and its geologic significance: Philippine Jour. Sci., v. 80, p. 55-88.
Isacks, B., J. Oliver, and L. R. Sykes, 1968, Seismology and the new global tectonics: Jour. Geophys. Research, v. 73, p. 5855-5899.
Juan, V. C., and Y. Wang, 1971, Taiwan in relation with the tectonic framework of the western Pacific: Taipei, Taiwan, Sino-American Science Cooperation Colloquium on Ocean Resources, v. 1, Marine geology and geophysics, p. 241-263.
Katsumata, M., and L. R. Sykes, 1969, Seismicity and tectonics of the western Pacific: Izu-Mariana-Caroline and Ryukyu-Taiwan regions: Jour. Geophys. Research, v. 74, p. 5923-5948.
Le Pichon, X., 1968, Sea-floor spreading and continental drift: Jour. Geophys. Research, v. 73, p. 3661-3697.
Ludwig, W. J., 1970, The Manila Trench and West Luzon Trough—3. Seismic-refraction measurements: Deep-Sea Research, v. 17, p. 553-571.
——— D. E. Hayes, and J. Ewing, 1967, The Manila Trench and West Luzon Trough—1. Bathymetry and sediment distribution: Deep-Sea Research, v. 14, p. 533-544.
May, M., R. A. Wehnau, K. Griffiths, and A. Most, 1969, Marine geological survey program 65-67, western North Pacific Ocean and South China Sea; Area 15, vol. 7—Ship operations, measurements at sea and data analysis procedures: Norwood, New Jersey, Alpine Geophys. Assoc., Inc., 98 p. (multilithed).
Meng, C.-Y., and S. S. L. Chang, 1971, The geologic structure of Taiwan: Taipei, Taiwan, Sino-American Science Cooperation Colloquium on Ocean Resources, v. 1, Marine geology and geophysics, p. 189-239.
Meyerhoff, A. A., 1970, Developments in mainland China, 1949-1968: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 1567-1580.
Morgan, W. J., 1968, Rises, trenches, great faults, and crustal blocks: Jour. Geophys. Research, v. 73, p. 1959-1982.
Niino, H., and K. O. Emery, 1961, Sediments of shallow portions of East China Sea and South China Sea: Geol. Soc. America Bull., v. 72, p. 731-762.
Oliver, J., 1970, Structure and evolution of the mobile seismic belts, *in* Geophysical studies of the earth's deep interior: Physics of the Earth and Planetary Interiors, v. 2, p. 350-362.
Pan, Y. S., 1967, The regional gravity of the Penghu Islands, Taiwan, China: Taiwan Petroleum Geology, v. 5, p. 117-129.
Parke, M. L., Jr., K. O. Emery, R. Szymankiewicz, and L. M. Reynolds, 1971, Structural framework of continental margin in South China Sea: Am. Assoc. Petroleum Geologists Bull., v. 55, p. 723-751.
Philippines Bureau of Mines, 1964, Geological map of the Philippines: scale 1:1,000,000, 8 sheets.
Rodolfo, K. S., 1969, Bathymetry and marine geology of the Andaman basin, and tectonic implications for southeast Asia: Geol. Soc. America Bull., v. 80, p. 1203-1230.
Todd, D. F., and A. Pulunggono, 1971, Wildcatters score in Indonesia: Oil and Gas Jour., v. 69, no. 24, p. 105-110.
U.S. Naval Oceanographic Office, 1967, Sailing directions for the western shores of South China Sea—Singapore Strait to Hong Kong, rev. ed.: U.S. Govt. Printing Office, H. O. Pub. 93.
van Bemmelen, R. W., 1949, The geology of Indonesia: The Hague, Martinus Nijhoff, v. 1, 732 p.; v. 2, 265 p.
Wageman, J. M., T. W. C. Hilde, and K. O. Emery, 1970, Structural framework of East China Sea and Yellow Sea: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 1611-1643.
Yen, T. P., 1971, Geology of Taiwan—A review especially on stratigraphy: Taipei, Taiwan, Sino-American Science Cooperation Colloquium on Ocean Resources, v. 1, Marine geology and geophysics, p. 1-24.